

Characterization of Atmospheric Mineral Dust from Radiometric and Polarimetric Remote Sensing

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LONG-TERM GOALS

The overall goal is to improve an understanding of the properties of mineral aerosols and their interactions with visible and IR atmospheric radiation, and to develop the dust optical models needed for new satellite radiometric and polarimetric sensors proposed for the NPOESS and other satellite missions.

OBJECTIVES

The main objectives of this research program are as follows:

- 1) develop advanced optical models of mineral dust required for the new generation of multi-channel, multi-angle remote sensors operating in the visible to IR spectral ranges;
- 2) develop robust techniques for discriminating dust from clouds and evaluate the contamination of aerosol signal by cloud scattering;
- 3) investigate the capability of polarimetric remote sensing to quantify dust microphysical and optical properties.

APPROACH

Our approach combines an extensive forward modeling, analysis of laboratory and in-situ data of dust microphysical, optical, and radiative properties, analysis of remotely sensed data from currently operating satellite sensors (such as MODIS, MISR and AIRS) as well as ground-based polarization measurements in the urban and dust-laden conditions.

WORK COMPLETED

FY07 is our final year of this three-year project. As part of this and past ONR-funded projects much effort has been devoted to developing improved modeling capabilities for the prediction of optical properties of multicomponent and non-spherical aerosols such as dust particles and their mixtures with other species. We have proposed a new technique to model optical characteristics of non-spherical dust

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particles (Kalashnikova and Sokolik, 2002, 2004). This technique combines dust particle composition-shape-size (CSS) distributions reconstructed from the electron microscopy data, effective medium approximations and discrete dipole approximation (DDA) method. Applying the technique to the recent data from the laboratory and experiments, a set of optical models for Asian and Saharan dust analogs was developed. These models were incorporated into the satellite Multi-Angle Imaging Radiometer (MISR) retrieval algorithm (Kalashnikova et al., 2005), resulting in successful retrievals of aerosol optical depth of the dust plumes over the ocean while Mie (spherical particles) optical models failed to retrieve dust. Furthermore, we have developed a measurement methodology which was specifically designed to determine iron oxides in dust aerosols as well as other key minerals that are needed for optical modeling from the visible to IR (Lafon et al., 2006). The recommendations on parameterizations of composition of dust for remote sensing were developed. In addition, we have computed new IR optical constants of multi-component aerosols consisting of ammonium sulfate, ammonium nitrate, sulfuric acid and nitric acid (Boer et al., 2007a, b). These new optical constants are of great relevance to IR high spectral resolution remote sensing. We also developed a one-dimensional radiative transfer model with polarization capable of computing the Stokes parameters taking into account multiple scattering and absorption of aerosol particles in multi-layered aerosol conditions. The model is capable of simulating the radiance and polarization in the presence of different aerosol external and/or internal mixtures consisting of various individual species. Overall, our models provide improved capabilities for characterization of aerosols from passive and active satellite sensors.

We have completed analyses of multi-year satellite observations of dust outbreaks over oceans. Analyses of satellite data from MODIS, MISR and TOMS was performed in conjunction with ground-based observations and a regional aerosol transport model (Darmenova et al., 2005). For the 2000-2004 time periods, we identified and characterized dust outbreaks over oceans originating from the main dust sources located in East and South Asia, Middle East, Northern Africa, and Australia. Using MODIS Terra Level 1B data containing calibrated and geolocated radiances, we investigated a regional signal of wind-blown mineral dust over the oceans and explore the implications to the dust detection over oceans with the techniques based on brightness temperature differences and the fixed STD-threshold. Several techniques proposed for detecting mineral dust using thermal-infrared observations (such as the split-window method and trispectral methods) were tested by analyzing brightness temperatures at three MODIS IR channels centered at 8.55, 11.03, and 12.02 μm for each dust event. We also investigated the spatial variability of visible radiances observed in the presence of mineral dust and clouds over oceans. We analyzed the satellite radiances by calculating standard deviations (STD) of the 3x3 pixels and the probability distribution function (PDF) of STD. In addition, we tested a local inhomogeneity parameter (LIP) method as an alternative approach. Based on this analysis we tested two statistical methods for the discrimination of dust from clouds utilizing the probability distribution functions of STD or LIP. Both methods provide continuous and simultaneous evaluation of a given pixel to be classified as cloudy, dusty, or mixed dust-cloud types. Performance of both methods was compared against the technique based on a fixed STD threshold, which is commonly used in passive remote sensing (e.g., MODIS and AVHRR).

RESULTS

The new techniques developed under this project were applied to several dust samples from Asian and African sources to determine the amount of iron oxides as well as the presence of minerals that are required to model the dust optical characteristics from the visible to IR. Based on these new data on size-resolved composition, the Chinese, Niger and Tunisian dust optical analogs were developed. We

demonstrate that variability of the amount of free and total iron content is large enough to cause important differences in the single scattering albedo of mineral dust originating from different sources, though this variability has little effect on the extinction coefficient and optical depth in the visible. In contrast, differing regional mineralogical compositions result in distinct differences in the spectral absorption and optical depth in the IR. To illustrate, Figure 1 shows that the single scattering albedo calculated from data obtained for Chinese and Tunisian dust samples have higher values and distinct wavelength dependence compared to those of Niger dust. All the single scattering albedo calculated with compositional data differ from ones calculated using the refractive indices of *Patterson et al.* (1977) or the OPAC model (*Hess et al.*, 1998), which are commonly used in remote sensing/climate studies.

Our analysis of satellite data revealed a distinct regional radiative signature of atmospheric dust. Figure 2 shows the brightness temperature differences calculated for MODIS IR channel for dust outbreaks originating from main dust sources. The regional radiative signature is likely due to the different mineralogical composition controlled by the diverse dust sources, although the multilayered vertical distribution of dust may also be important. Thus it will be required to consider the origin of atmospheric dust in order to utilize the dust detection technique based on brightness temperature differences in their full potential. Several recommendations were developed to improve dust detection with IR remote sensing.

We demonstrated that the current MODIS aerosol/cloud mask which is based on the fixed-STD threshold has several critical biases. Our analysis revealed that introducing the probability distribution function of the standard deviation (STD) of visible radiances has a high potential for the improved discrimination of dust from clouds over oceans. Our work provides a conceptual basis for the development of a new probabilistic cloud/mask for passive remote sensing. The probabilistic approach is not only superior to the common fixed STD method in discriminating dust from clouds, but also offers a number of advantages such as detection of dust-cloud mixed scenes in addition to “pure” dust and “pure” cloud pixels.

IMPACT/APPLICATIONS

New techniques, dust optical models, and IR optical constants that were developed under this project are of interest to ONR remote sensing and aerosol-related applications as well as to the large scientific community involved in the passive and active remote sensing from the UV to IR. Our dust models were incorporated into the MISR aerosol retrieval algorithm. The scattering phase functions are being used in the CALIPSO retrieval algorithm of aerosol optical depth. Results of our work will help to improve the retrieval algorithms that are being developed for the future NPOESS/VIIRS.

TRANSITIONS

Our main results were published in peer-reviewed journals and presented at numerous scientific meetings.

RELATED PROJECTS

Several NASA-funded projects are related to this project. For NASA we have been working on developing the non-spherical dust models for the space lidar CALIPSO as well as to improve dust models and dust detection in MISR. Overall, our research has the high potential to provide a framework for the development of the new generation of aerosol models required for both passive and active remote sensing from the UV to the IR, as well as for improved prediction of impacts of dust aerosols on climate and health.

PUBLICATIONS in FY2007

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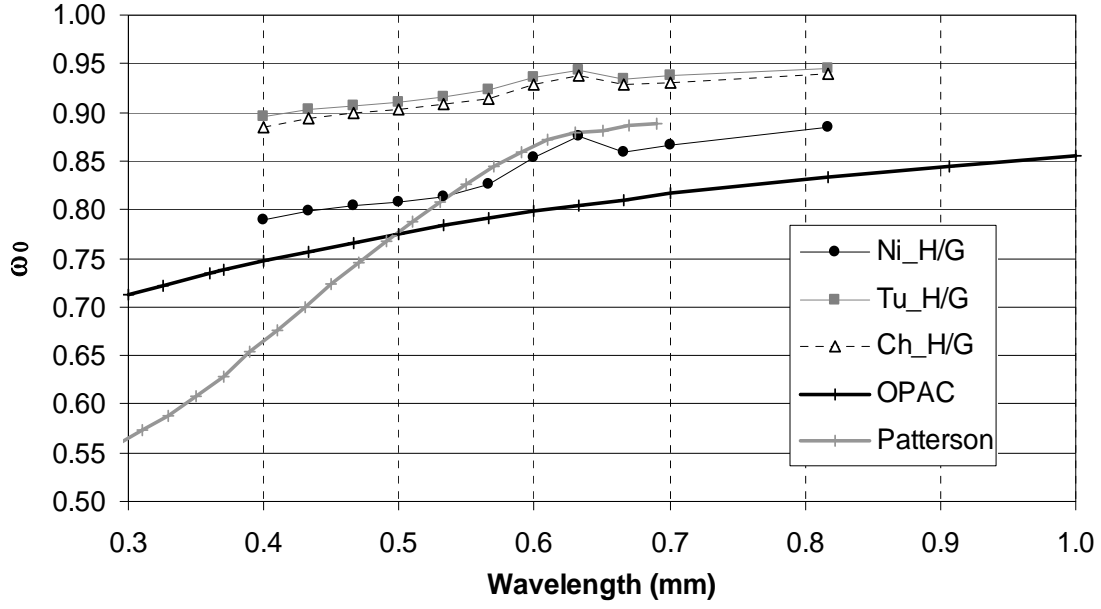


Figure 1. Single scattering albedo as a function of wavelength computed for Niger, Tunisian, and Chinese dust samples by taking into account all relevant data on size-resolved composition obtained in this project. Single scattering albedos calculated with the OPAC and Patterson et al. refractive indices are also shown for comparison.

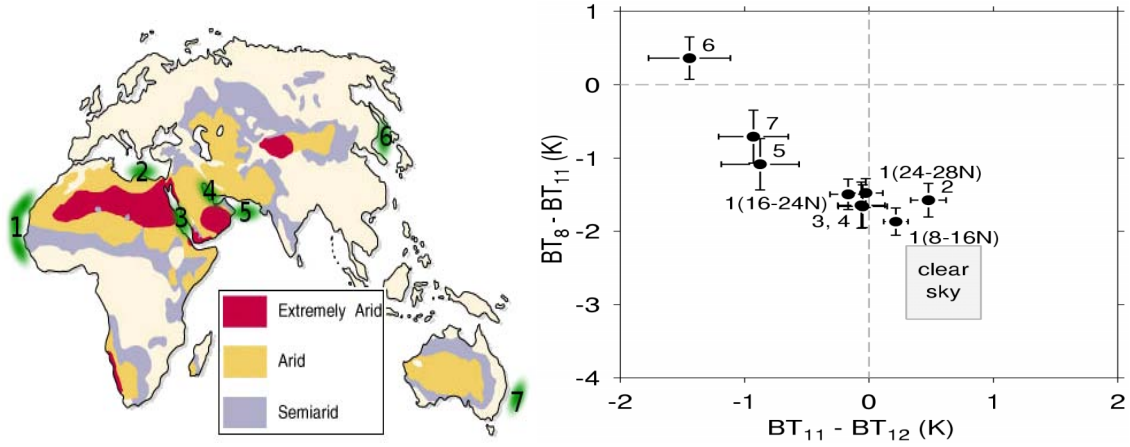


Figure 2. Brightness temperature differences for “heavy dust” cases based on the four year MODIS observations of dust outbreaks over oceans. The map shows the geographical regions considered in our analysis.